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by

Zhili Liu, Yihe Yang, Weizhen Zhou

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NEW IMAGE-TRACKING ALGORITHM FOR FUZZY-RELAXATION MATCHING OF POINT PATTERNS

Liu Zhili, North China Research Institute of Electro-Optics, Beijing, and Yang Yihe and Zhou Weizhen, Department of Technical Physics, Xi'an University of Electronics Science and Technology

Abstract

The paper presents a new image-tracking algorithm for fuzzy-relaxation matching of point-patterns. The algorithm is insensitive to geometric distortions of the whole, to inaffine distortions to a certain extent, and to multi- and few-point distortions. The presentation of the new matching-vector set and the standard set greatly reduces computation time. As shown by simulation results of multi-target infrared image array in the sea, the algorithm is adaptable not only to a single target, but also to multiple targets in acquisition, locating, and tracking.

Key words: image tracking, graphic matching, and graphic recalibration.

I. Introduction

During the initial stage of guidance by a tracker, since the target is relatively far away, the target image is relatively small; there are many targets in the visual field, in addition to

considerable interference in the background, mass-center trackers and the correlation trackers are not suitable. During a flight process, the visual angle continually varies; in addition, there is a certain degree of geometric distortions (rotation, amplification and translational motion) existing between frames, so perspective distortions and local inaffine distortions are present. Possibly, the interframe point patterns are not identical.

By using the matching algorithm, the authors solved the problem of image distortions confronted during the initial guidance stage. In addition, the authors selected point-pattern type point sets, constituting mass centers in the target zone. With the other geometric characteristics or physical characteristics as supplements, the point-pattern type interpoint space structure relation is utilized to conduct point-pattern type matching tracking, thus basically solving the problems of geometric distortions, perspective distortions, local inaffine distortions, and multi- and few-point situations of interframe point-pattern type.

The algorithm can be used to intercept the target visual field from the target launching as well as to observe the servo-motions in the visual field, thus eliminating the transient violent disturbances during launching and to conduct locating and tracking of the attacking target.

2, Matching Algorithm for Fuzzy-Relaxation Matching of Point Patterns

Select the ratio between the square of the circumference length and area in the target as the supplementary characteristic, which has the constant features of rotation, amplification, and translational motion. The mass centers in the target zone constitute a point-pattern type; by introducing the

concept of standard vector, the computation speed is increased. By introducing the vector space and utilizing the mean-variance minimum criterion, we can derive the function in describing space-structure relation similarity of the vector. Then by using the supplementary vectors, the iterative process of fuzzy-relaxation matching is conducted until the iterative process approaches a steady state.

The mathematical model of point-pattern type: by using the mass centers in the target zone as coordinates (X, Y) in the target zone, different concrete problems select different supplementary characteristics. After a large number of experiments, the authors selected P^2/A as the supplementary characteristic; refer to [1] for the selection of supplementary characteristics; refer to [2] for the method of computing characteristic values.

M and W represent, respectively, the reference point-pattern type and the real-time point-pattern type. There is a total of m points in M; and there is a total of n points in W.

$$M=\{P_i\}=\{(X_{p_i}, Y_{p_i}, F_{p_i})\},\ i=\overline{1, m};$$
$$W=\{Q_j\}=\{X_{q_j}, Y_{q_j}, F_{q_j})\},\ j=\overline{1, m,}$$

2.1. Vector Sets in Fuzzy-Relaxation Matching

(1) Prefiltered wave

By utilizing a simple characteristic value and the threshold value method, very dissimilar points are eliminated. First, solve for the additional limitation F_0 of the maximum value F_{max} and the minimum value F_{min} of $P_i(i=\overline{1, m})$ characteristic value F_{pi} in M. Then all characteristic values F_{qj} are compared to the threshold values of $Q_j(j=\overline{1, n})$ in W, if $F_{q_j}<F_{min}-F_0$ or $F_{q_j}>F_{max}+F_0$, remove Q_j point in W; otherwise, retain the Q_j point.

(2) Obtaining vector Ω_M in M

In order to reduce the possible number of matching vectors, the attacking target (T) can be selected as the vector starting point, and other points (u) in M as the endpoint, thus constituting a vector set Ω_M as shown in Fig. 1. $P_{\overrightarrow{TU}}$ is the concentrated vector in Ω_M. In order to further reduce the computational volume, the authors introduce the concept of standard vector. The key to establishing the standard vector is based on selecting the endpoint B; refer to the two following statements for the selection principle: (i) the characteristics of point B are more apparent than those of other points (other than T) in M; and (ii) point B certainly exists in W; it is neither too close nor too far between point B and point T, such as

$$|P_{\overrightarrow{TB}}| MEDIAN\{|P_{\overrightarrow{UB}}|\}.$$

(3) Obtaining vector set Ω_M in the point set W

Any two points in W can constitute a vector. In order to reduce the number of possible vectors, a criterion is introduced. Let P_i be the starting point in Ω_M and let P_k be the endpoint, thus constituting vector $P_{\vec{ik}}$. In Ω_M, Q_j is the starting point, and Q_l is the endpoint, thus constituting a vector $Q_{\vec{jl}}$. Let us introduce the function

$$C^{(0)}(P_{\vec{ik}}, Q_{\vec{jl}}) = 1/[1+\beta\cdot(\bar{F}_{pi}-\bar{F}_{qj})^2+\beta(\bar{F}_{pk}-\bar{F}_{ql})^2]. \tag{1}$$

Select threshold value l, if $C^{(0)}(P_{\vec{ik}}, Q_{\vec{jl}}) > l$, then determine the vector in Ω_M, otherwise reject it. Refer to Fig. 2 for the Ω_W set.

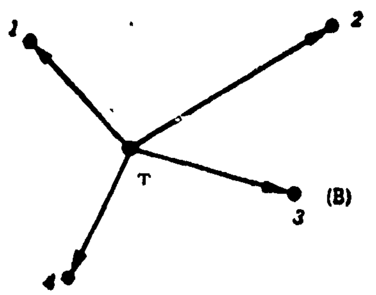

Fig. 1. Vector set Ω_M

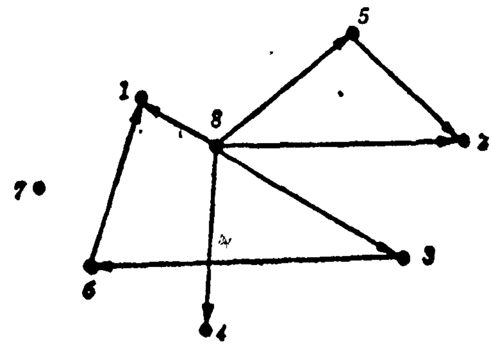

Fig. 2. Vector set Ω_W

2.2. Tracking algorithm for fuzzy-relaxation matching

(1) Similarity function $G\{(P_{\vec{ik}}, Q_{\vec{jl}}), (P_{\vec{mu}}, Q_{\vec{tv}})\}$

When one compares the degree of similarity of space structures of $P_{\vec{ik}}$ and $Q_{\vec{jl}}$ vectors, let us introduce $P_{\vec{mu}} \in \Omega_M (P_{\vec{mu}} \neq P_{\vec{ik}})$ and $Q_{\vec{tv}} \in \Omega_W$ $(Q_{\vec{tv}} \neq Q_{\vec{jl}})$ as the supplementary vector pair. With $G\{\cdot\}$ we describe the degree of similarity of space structure relations of vector pair $(P_{\vec{ik}}, P_{\vec{mu}})$. in Ω_M and vector pair $(Q_{\vec{jl}}, Q_{\vec{tv}})$ in Ω_W.

Assume

$$P = \{P_i, P_k, P_m, P_u\} = \{P_1, P_2, P_3, P_4\} = \{P_j\}$$
$$\dot{Q} = \{Q_j, Q_l, Q_t, Q_v\} = \{Q_1, Q_2, Q_3, Q_4\} = \{Q_j\}$$

The coordinates P_j and Q_j are expressed as complex numbers

$$P_j = X_{p,j} + iY_{p,j}; \quad Q_j = X_{q,j} + iY_{q,j}$$

$Z = Z_1 + iZ_2$, describes the rotation and amplification quantities;

$W = W_1 + iW_2$ describes the translational motion.

After linear transformation $\Phi(Z, W)$, Q_j is converted into $\hat{Q}_j$,

$$\hat{Q}_j = ZQ_j + W.$$

Let

$$\begin{aligned} X_p &= (X_{p1}, X_{p2}, X_{p3}, X_{p4}); \\ Y_p &= (Y_{p1}, Y_{p2}, Y_{p3}, Y_{p4}); \\ X_q &= (X_{q1}, X_{q2}, X_{q3}, X_{q4}); \\ Y_q &= (Y_{q1}, Y_{q2}, Y_{q3}, Y_{q4}); \\ U &= (1, 1, 1, 1); \end{aligned}$$

Then

$$\begin{aligned} \hat{X}_{qj} &= Z_1 \cdot X_{qj} - Z_2 \cdot Y_{qj} + W_1; \\ \hat{Y}_{qj} &= Z_2 \cdot X_{qj} + Z_1 \cdot Y_{qj} + W_2. \end{aligned}$$

Let us use the distance and the minimum between the corresponding starting point and the corresponding endpoint of the matching vector and the supplementary matching vector as the criterion.

$$\begin{aligned} \varepsilon^2 &= \underset{\Phi(Z,W)}{MIN} \left\{ \sum_{j=1}^{4} |P_j - \hat{Q}_j|^2 \right\} \\ &= \sum_{j=1}^{4} \{(X_{pj} - Z_1 \cdot X_{qj} + Z_2 \cdot Y_{qj} - W_1)^2 + (Y_{pj} - Z_1 \cdot Y_{qj} - Z_2 \cdot X_{qj} - W_2)^2\}; \end{aligned}$$

Let $\epsilon^2 = 0$, the above equation can be rewritten in matrix form

$$\begin{bmatrix} X_q^T X_q + Y_q^T Y_q & 0 & X_q^T U & X_q^T U \\ 0 & X_q^T X_q + Y_q^T Y_q & -Y_q^T U & -Y_p^T \cdot U \\ X_q U & -Y_q U & 4 & 0 \\ Y_q U & X_q \cdot U & 0 & 4 \end{bmatrix} \cdot \begin{bmatrix} Z_1 \\ Z_2 \\ W_1 \\ W_2 \end{bmatrix} = \begin{bmatrix} X_p^T X_q + Y_p^T \cdot Y_q \\ Y_p^T \cdot X_q - X_p^T \cdot Y_q \\ X_j^T U \\ Y_p^T U \end{bmatrix};$$

Thus we derive

$$Z_1=[4X_p^T\cdot X_q+4Y_p^T\cdot Y_q-(X_q^T\cdot U)\cdot(X_p^T\cdot U)-(Y_q^TU)\cdot(Y_p^TU)]/a;$$

$$Z_2=[4Y_p^T\cdot X_q-4X_p^T\cdot Y_q+(Y_q^TU)\cdot(X_p^TU)-(X_q^TU)\cdot(Y_p^TU)]/a;$$

$$W_1=[(X_q^TX_q+Y_q^TY_q)\cdot(X_p^TU)-(X_p^T\cdot X_q+Y_p^T\cdot Y_q)(X_q^TU)$$
$$+(Y_p^T\cdot X_q-X_p^TY_q)\cdot(Y_q^T\cdot U)]/a;$$

$$W_2=[(X_q^TX_q+Y_q^TY_q)\cdot(Y_p^T\cdot U)-(X_p^T\cdot X_q+Y_p^T\cdot Y_q)(Y_q^TU)$$
$$-(Y_p^T\cdot X_q-X_p^T\cdot Y_q)(X_q^T\cdot V)]/a;$$

$$a=4X_q^T\cdot X_q+4Y_q^T\cdot Y_q-(X_q^T\cdot u)^2-(Y_q^T\cdot u)^2.$$

The greater the similarity between the space structure relation of vector pair $(P_{\vec{ik}}, P_{\vec{su}})$ in Ω_M and the space structure relation of vector pair $(Q_{\vec{jl}}, Q_{\vec{tv}})$. in Ω_W, the smaller the value of ϵ^2, the greater the value of $G\{\cdot\}$. The $G\{\cdot\}$ equation is

$$G\{(P_{\vec{ik}}, Q_{\vec{jl}}), (P_{\vec{su}}, Q_{\vec{tv}})\}=1/(1+\alpha\cdot\varepsilon^2),$$
$$= \text{const},\ 0<G\{\cdot\}\leqslant 1. \qquad (2)$$

(2) Iterative matching process of fuzzy relaxation.

Mainly, the space structure relation is adopted in the fuzzy-relaxation matching algorithm; the assigned classification uses the characteristic value as a supplement; the degree of assigning is expressed by the degree of subordination. By utilizing the space structure similarity function, $G\{\cdot\}$, gradual revisions are made of the degree of classification subordination until a relatively stable degree of subordination is reached. By matching Ω_M and Ω_W, actually this is based on a comparison of degrees of similarity of various vectors in Ω_W by a certain vector in Ω_M to arrive at a subordination classification. For a certain vector $P_{\vec{ik}}$ in Ω_M, when determining the degree of subordination of vectors $Q_{\vec{jl}}$ in $P_{\vec{ik}}$ and Ω_W, consideration is given to seeking a vector $Q_{\vec{tv}}(Q_{\vec{tv}}\neq Q_{\vec{jl}})$ in Ω_W for each vector $P_{\vec{su}}$ to each vector $P_{\vec{su}}(P_{\vec{su}}\neq P_{\vec{kl}})$ in Ω_M, so that the space structure relation between Q_{tx} and $Q_{\vec{jl}}$ and the space structure relation between $P_{\vec{su}}$ and $P_{\vec{ik}}$ is the most similar.

$C^{(n)}(P_{\vec{i}\vec{k}}, Q_{\vec{j}}$ describes the fact that the degree of subordination of $P_{\vec{i}\vec{k}}$ subordinating to $Q_{\vec{j}\vec{l}}$ in an n-th iterative process. The contribution made by each supplementary vector pair $(P_{\vec{s}\vec{u}}, Q_{\vec{t}\vec{v}})$ to $C^{(n)}(P_{\vec{i}\vec{k}}, Q_{\vec{j}\vec{l}})$ is made up of two parts:

(i) $C^{(n-1)}(P_{\vec{s}\vec{u}}, Q_{\vec{t}\vec{v}})$ describes the degree of subordination of $P_{\vec{s}\vec{u}}$ subordinating to $Q_{\vec{t}\vec{v}}$ in the (n - 1)-th iterative process;

(ii) the space structure similarity function

$$G\{(P_{\vec{i}\vec{k}}, Q_{\vec{j}\vec{l}}), (P_{\vec{s}\vec{u}}, Q_{\vec{t}\vec{v}})\};$$

If $P_{\vec{i}\vec{k}}$ and $Q_{\vec{j}\vec{l}}$ are matching vectors, then both are relatively large; otherwise, at least one of the two is relatively smaller. We adopt a cautious principle

$$MIN\{G[(P_{\vec{i}\vec{k}}, Q_{\vec{j}\vec{l}}), (P_{\vec{s}\vec{n}}, Q_{\vec{t}\vec{v}})], \\ C^{(n-1)}(P_{\vec{s}\vec{u}}, Q_{\vec{t}\vec{v}})\}$$

After picking $P_{\vec{s}\vec{u}} \in \Omega_M$ as the supplementary vector, different $Q_{\vec{t}\vec{v}} \in \Omega_W$ make different contributions to $C^{(n)}(\cdot)$; the largest contribution is

$$\underset{\substack{Q_{\vec{t}\vec{v}} \in \Omega_w \\ Q_{\vec{t}\vec{v}} \neq Q_{\vec{j}\vec{l}}}}{MAX}\{MIN[G((P_{\vec{i}\vec{k}}, Q_{\vec{j}\vec{l}}), \\ (P_{\vec{s}\vec{u}}, Q_{\vec{t}\vec{v}})), C^{(n-1)}(P_{\vec{s}\vec{u}}, Q_{\vec{t}\vec{v}})]\}.$$

If $P_{\vec{i}\vec{k}}$ and $Q_{\vec{j}\vec{l}}$ are matching vectors, then there should be the corresponding matching supplementary vectors $P_{\vec{s}\vec{u}}$ and $Q_{\vec{t}\vec{v}}$, then the above equation yields larger values.

If there is a match between $P_{\vec{i}\vec{k}}$ and $Q_{\vec{j}\vec{l}}$, then all $P_{\vec{s}\vec{u}}$ can find the corresponding $Q_{\vec{t}\vec{v}}$ vector in Ω_W so that the space structure relation constituted by $Q_{\vec{t}\vec{v}}$ and $Q_{\vec{j}\vec{l}}$ is similar to the space structure relation constituted by $P_{\vec{s}\vec{u}}$ and $P_{\vec{i}\vec{k}}$. Based on the principle of caution, $C^{(n)}(P_{\vec{i}\vec{k}}, Q_{\vec{j}\vec{l}})$ cannot be larger than the minimum value in the above-mentioned equation of all the derived $P_{\vec{s}\vec{u}} \in \Omega_M$ supplementary vectors. Therefore, the iterative process of fuzzy-relaxation matching can be written as follows:

$$O^{(n)}(P_{\vec{ik}}, Q_{\vec{jl}}) = \underset{\substack{P_{\vec{i}l}Q \in \Omega_M \quad Q_{\vec{tr}} \in \Omega_W \\ P_{\vec{ik}} \neq P_{\vec{jl}} \quad Q_{\vec{tr}} \neq Q_{\vec{tv}}}}{MIN} \{MAX\{ MIN[G[(P_{\vec{il}}, Q_{\vec{jl}}), (P_{\vec{su}}, Q_{\vec{tv}})], \quad O^{(n-1)}(P_{\vec{su}}, Q_{\vec{tv}})]\}\}. \tag{3}$$

The initial value of the iterative process is determined by the characteristic value. From Eq. (1), after several times (generally two times is enough) of iterative substitution, all $O^{(n)}(P_{\vec{ik}}, Q_{\vec{jl}})$ values approach a steady-state. For $Q_{\vec{jl}}$ vectors corresponding to a $P_{\vec{ik}}$ vector, the maximum $Q_{\vec{jl}}$ of $O^{(n)}(P_{\vec{ik}}, Q_{\vec{jl}})$ value selected as the matching vector of $P_{\vec{ik}}$. The corresponding pair of starting points and the pair of endpoints of the matching vector are the corresponding matching points in M and W. Actually, this is enough to satisfy

$$|O^{(n)}(P_{\vec{ik}}, Q_{\vec{jl}}) - O^{(n-1)}(P_{\vec{ik}}, Q_{\vec{jl}})| < P$$

(3) Obtaining tracking signals

After the tracking algorithm of fuzzy-relaxation matching is applied, we obtain the signals of attacking target T (or multiple targets) and tracking (rotation, amplification, and translational motion parameters between the real-time point-pattern type and the reference point-pattern type). In these parameters, the rotation angle θ is $\theta = \arctan(Z_2/Z_1)$; amplification times S is $S = \sqrt{Z_1^2 + Z_2^2}$; and translational motion (b, K) is $n = W_1$; $K = W_2$.

2.3. Analysis of real-time features

Fig. 3 is a figure for analysis of real-time characteristics. As shown by a detailed analysis, if the number of iterative substitutions is r, there are m vectors in Ω_M and there are n vectors in Ω_W, each computation time is 0.1 μs, then the total computation time t required is $t = 37.2(m - 1)(n - 1) \cdot r$; assume m = 5, n = 8, r = 4, then the computation time (4.2 ms) is less than 20 ms; therefore, this is

real time. In actual computation, time is hardware design-dependent.

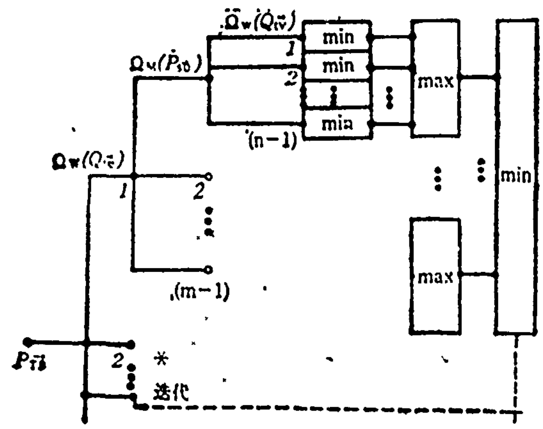

Fig. 3. Illustration for real-time analysis
KEY: * iterative substitution

III. Target Simulation Experiments in the Sea

The authors conducted simulation experiments (refer to Fig. 4 (a, b, c) by utilizing a multi-target infrared image array in and on the sea. In Fig. 4 (a) and Fig. 4 (b), there are four targets: A, B, C, and D. Fig. 4 (c) is obtained from Fig. 4 (a) by artificially eliminating target D and simultaneously adding targets E, F, and G (a total of six targets). There are geometric distortions as a whole, inaffine-geometric distortions, and perspective distortions exist between Fig. 4 (a) and Fig. 4 (b). In addition to the above-mentioned distortions between Fig. 4 (c) and Fig. 4 (a), and between Fig. 4 (c) and Fig. 4 (b), there are multi- and few-point distortions.

Fig. 4 (a). Image in series No. 1

Fig. 4 (b). Image in series No. 2

Fig. 4 (c). Image in series No. 3

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